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Friction and wear of electroless NiP and NiP + PTFE coatings

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Abstract

In the past 30 years, electroless nickel (EN) plating has grown to such proportions that these coatings are now found underground, in outer space, and in a myriad of areas in between. The first criteria to use electroless nickel generally falls within the following categories: corrosion and wear resistance, hardness, lubricity, uniformity of deposit regardless of geometries, solderability and bondability and nonmagnetic properties. An important property is the amorphous structure in the as-plated condition and the ability to heat treat the deposit by precipitation hardening. Moreover, in order to improve the mechanical and tribological properties of the EN coatings (NiP) further, a EN-polytetrafluoroethylene (NiP + PTFE) composite coating can be obtained that provides even greater lubricity than that which naturally occurs in the nickel–phosphorous alloy deposit. The aim of the present work was an investigation of the friction and wear characteristics of NiP and NiP + PTFE coatings in sliding contacts against hard chromium steel. The role of heat treatment of the coating is discussed.

Keywords: Wear; Friction; Dissipated energy; Electroless coatings

1. Introduction

It is well known that the electroless nickel (EN) coating is the autocatalytic deposition of a NiP alloy from an aqueous solution into a substrate without the application of an electric current. EN coatings provide material properties that expand the physical properties beyond those of pure nickel coating systems. These coatings are widely used in the mechanical, chemical and electronic industries because of their corrosion and wear resistance, hardness, lubricity, uniformity of deposit regardless of geometries, solderability and bondability and nonmagnetic properties [1].

The mechanical and tribological properties of these deposits can be further improved by the incorporation of hard particles (SiC, B_4C, Al_2O_3 and diamond) [2,3] and dry lubricants (PTFE, MoS_2 and graphite) [1,3–5], resulting in this case in a film with self-lubricating and excellent anti-sticking characteristics.

The properties and microstructure of EN coatings depend on the post-deposition heat treatment, which is frequently used to improve adhesion or to modify properties in order to satisfy the needs of a particular application. In this case, and with an appropriate temperature used in the heat treatment, there is an increase in the hardness reaching even that of commercial hard chromium coatings [2,6]. Therefore, for some applications, EN can be a good alternative to the chromium coatings without the negative environmental impact due to the chromium deposition [6–8]. As a result of heat treatment, the characteristics of the deposit can be changed, namely: wear, corrosion and fatigue resistance, hardness, ductility, magnetic properties and other. Maximum hardness can be achieved after a 1-h heat treatment above 360 °C, depending on the phosphorous content [1,2,9]. This has been attributed to fine Ni crystallites and hard intermetallic Ni_3P particles precipitated during the crystallization of the amorphous phase [9,10]. Depending on the conditions of the heat treatment, the structure of the EN coatings has been reported to be either crystalline, amorphous or a mixture of both.

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The present work aims to investigate the friction and wear characteristics of NiP and NiP + PTFE coatings in sliding contacts against hard chromium steel. The role of heat treatment of the coating is discussed.

2. Experimental details

Friction and wear were experimentally studied using a sliding tribometer with crossed cylinder contact (Fig. 1). The equipment included a rotating specimen with cylindrical shape (3) and a smaller cylindrical stationary specimen (5). The normal load was applied by a spindle/spring system (4) and was measured by a load cell (1). The stationary specimen, a hard steel AISI 52100 with 750HV30, with a diameter of 10 mm, was supported by a free rotating system, which was equilibrated by a second load cell (2) used to measure the friction force. The diameter of the rotating disc was 60 mm and the rotation speed 159 rpm, thus, the sliding speed was 0.5 m/s. This disk, of a hard high-speed steel AISI M2 quenched and tempered with 880HV30, was used as a substrate to deposit the EN coatings. The normal load was in the range from 2 to 35 N and the test duration from 4 min to 30 h, which correspond to a sliding distance from 120 to 54,000 m.

The coatings were produced in an industrial plant by Tecnocrom Industrial S.A. (Barcelona, Spain) using commercial electroless nickel solutions.

Five materials were tested against AISI 52100, namely, NiP as-plated, NiP heat treated (HT NiP), NiP + PTFE as-plated, NiP + PTFE heat treated (HT NiP + PTFE), and uncoated AISI M2 steel.

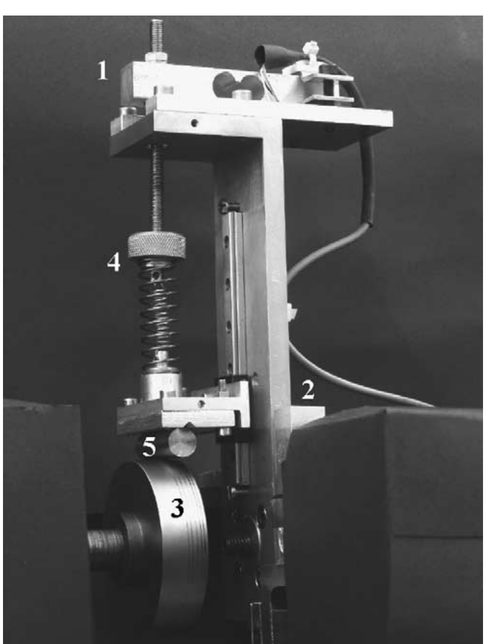

Fig. 1. Sliding tribometer with crossed cylinder contact.

Before testing, the specimens were cleaned with ethylic alcohol. During the test, the friction force value was periodically acquired, with time intervals of Δt. In each acquisition, a set of several thousand values was collected, corresponding to an acquisition time larger than the rotation period. Therefore, the average values of the friction force, $\overline{F}_a$ calculated from each set of acquired data, correspond to the average value of the friction. The friction that exists in the crossed cylinder contact is responsible for an energy dissipation [11,12]. This fact leads to the occurrence of wear in the materials. Considering that the friction is the most important process related to the changes in the system energy, it would inevitably play an important role in the wear losses. In this way, the energy dissipated in the contact can be calculated as the work of the friction force. For each time interval Δt, to which corresponds a displacement Δx, the dissipated energy ΔE can be achieved by Eq. (1). Considering the average value of the friction force and assuming a constant sliding speed V_t, Eq. (2) can be used.

$$\Delta E = \int_0^{\Delta l} F_a \, dx = \int_0^{\Delta t} F_a \, V_t \, dt \tag{1}$$

$$\Delta E = \overline{F}_a \, V_t \, \Delta t \tag{2}$$

The total energy dissipated during the test can be calculated by adding all the ΔE calculated throughout the test. At the end of the test the stationary specimen shows an elliptical-shaped wear scar (Fig. 2).

On the rotating specimen, the wear produces a circumferential track. For the stationary specimen, the volume of the wear scar can be calculated assuming an imposed wear shape using the approximate expression (3) derived by Ramalho [13]. This simple equation is very accurate with errors smaller than 0.2% [13].

$$V = \frac{\pi}{2} h^2 \sqrt{d_1 d_2} \tag{3}$$

where d_1 is the diameter of the stationary specimen, d_2 is the diameter of the rotating specimen, and h is the depth of the scar.

Each scar is measured by taking the dimensions of the larger, a, and the smaller, b, dimensions of the wear surface

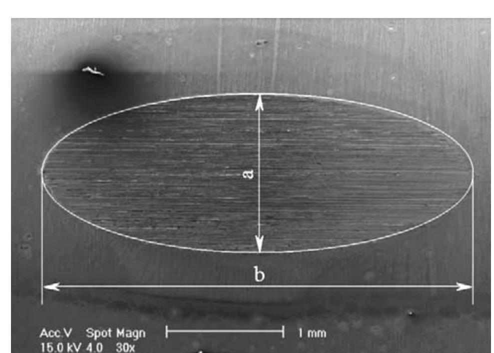

Fig. 2. Typical wear scar of the stationary specimen.